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Low Temperature Microgravity Physics Facility

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ABSTRACT

We present here a brief overview of the of the Microgravity Fundamental Physics discipline requirements for a Low Temperature Microgravity Physics Facility and describe the plans for the development of this facility which will be attached to the Japanese Experiment Module Exposed Facility on board the International Space Station.

1. INTRODUCTION

Microgravity Fundamental Physics (MFP) has emerged as a discipline with the support of the Microgravity Research Division of NASA headquarters. As a discipline it supports the first goal of the Human Exploration and Development of Space directive (HEDS), which reads "to understand and use nature's processes in space". The broadest goal of Microgravity Fundamental Physics is to establish a unified description and understanding of fundamental laws governing the complex phenomena in our world at microscopic, macroscopic and cosmic scales of length and time by utilizing the microgravity environment. Microgravity Fundamental Physics encompasses sub-fields with specific problems that can benefit from the dramatically reduced gravity available in space or from the use of gravity as a parameter whose change may lead to the elucidation of otherwise hidden properties and phenomena. These include sub-fields where extremely uniform samples free from hydrostatic compression are required or where objects must be freely suspended. Currently, there are three sub-disciplines of MFP: Low Temperature Condensed Matter Physics (LT/CMP), Laser Cooling and Atomic Physics (LCAP) and Relativity and Gravitational Physics (GRP). LT/CMP evolved from Low Temperature Physics, which was initially a sub-discipline of Fluid Physics. For historical reasons, CMP is the more mature of the sub-disciplines and has currently 34 investigations (1 Nobel Prize PI), with 6 of those being flight definition projects. LCAP and GRP are emerging sub-disciplines with 14 (1 Nobel Prize PI) and 6 investigations, respectively. There were three flight experiments to date, all in LT/CMP. In 1985 the Superfluid Helium Experiment[1], developed by the Jet Propulsion Laboratory, demonstrated the containment and control of liquid helium aboard the space shuttle and the feasibility of supporting a science instrument insert within a liquid helium dewar. In 1992 the Lambda Point Experiment (LPE)[2], developed by Stanford University, JPL and Ball Aerospace Technology Corporation, added nanokelvin high-resolution thermometry to this capability which allowed a precise test of the Nobel Prize winning Renormalization Group (RG) theory of critical phenomenon[3]. In 1997, the Confined Helium Experiment (CheX) used the unique properties of liquid helium to perform a high-resolution test of the theory of finite size effects[4].

Future LT/CMP (and some GRP) experiments are slated to be performed on the Low Temperature Microgravity Physics Facility (LTMPF), which will be an attached payload to the Japanese Experiment Module Exposed Facility (JEMEF). It will accommodate two experiments and will have a lifetime of 6 months. After exhausting its lifetime it be passive until a shuttle flight returns it to the ground for refitting with a second dewar with two new experiments. The facility with its two new experiments is launched for another 6-month period. Flights are scheduled for every two years.

There are currently six flight definition experiments that will compete for the first two slots on the facility. The Microgravity Scaling Theory Experiment (MISTE)* will perform very precise measurements of thermodynamic properties near the liquid-vapor critical point of ^{3}He. In particular, MISTE will measure the heat capacity exponent α, the isothermal compressibility γ, and the exponent characterizing the relation between the pressure and density along the critical isotherm δ. These exponents will be used for a self-consisting test of scaling law predictions. The Superfluid Universality Experiment (SUE)† will measure the

* Principal Investigator: M. Barmatz, JPL.
† Principal Investigator: J.A. Lipa, Stanford University.

superfluid density exponent along the lambda line of helium in microgravity. These measurements along with measurements of the heat capacity exponent along the lambda line in the 0.01 g facility at JPL[5] will be used to check the universality prediction by the theory of critical phenomena. The Critical Dynamics in Microgravity Experiment (DYNAMX) will study the rich, largely unexplored, properties of superfluid helium driven away from equilibrium by the introduction of a heat current[‡]. Thermal conductivity data in the non-linear region will be collected as well as heat capacity data just below the superfluid transition. BEST combines two projects (Boundary Effects on Transport Properties and Dynamic Finite-size Scaling Near the Superfluid-Transition Line of 4He[§] and Critical Thermal Transport in a Cross-over Range from 3-Dimensional to 2-Dimensional Behavior[**]) to investigate the influence of dimensionality and finite size effects on the transport properties of ^{4}He near the superfluid transition. Experiments Along the Coexistence Line Near Tri-criticality[††] (EXACT) will test exact predictions of Renormalization Group Theory by using second sound and dielectric constant measurements near the tricritical point in ^{3}He-^{4}He mixtures. The second sound velocity is proportional to the superfluid density, which is predicted for 3D systems with order parameters with a finite number of components to have an integer fraction with a logarithmic correction as the critical exponent. Fundamental Physics Experiments with Superconducting Cavity - Stabilized Oscillators on Space Station (EXSCSO)[‡‡] is a GRP experiment that will utilize LTMPF. This experiment will perform a red-shift test of general relativity using a pair of superconducting cavity stabilized clocks. The red shift will be measured to better than 1 PPM. One of the units will be installed on the Space Station and the other will remain on the shuttle. The experimental measurement will consist of detecting the relative signal from the two clocks when the shuttle is placed in a slightly elliptical orbit synchronous with that of the space station.

Low Temperature Microgravity Physics Facility

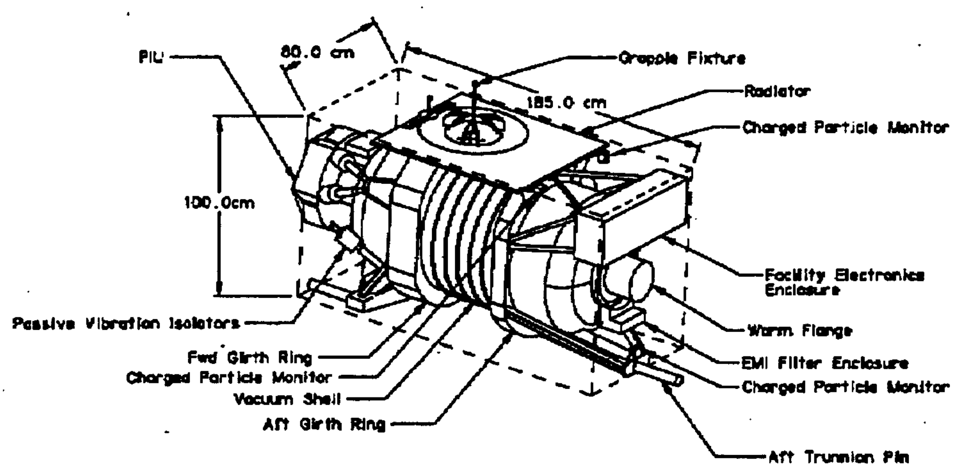

Figure 1

2. DESIGN REQUIREMENTS

To reduce the cost per experiment, the facility will accommodate two experiments simultaneously. Based on a survey of the experiments currently funded, it was determined that the lifetime of the

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[**] Principal Investigator: F.C. Liu, JPL.
[††] Principal Investigator: M.Larson, JPL
[‡‡] Principal Investigator: J.A. Lipa, Stanford University

cryogen should be at least six months. This survey also determined that a suitably modified LPE-like instrument insert would be adequate for all the experiments. All experiments seem to be sensitive more or less severely by the impact of cosmic rays and by the radiation environment, so radiation monitoring should be provided. Since the vibration environment is unknown at this point, and most experiments are sensitive to acceleration (DC and AC), some degree of vibration isolation as well as the means to monitor the acceleration levels will have to be provided.

3. FACILITY DESCRIPTION

LTMPF will be implemented by a science, industry and JPL partnership of joint participation through all phases of definition, development and test. JPL, as the NASA center of excellence for fundamental microgravity physics, will be responsible for development of the instruments and management of the overall activity. The industry partner, Ball Aerospace Technology Corporation was selected through a competitive technical selection process. BATC will be responsible for the development of the facility flight hardware, except for the instruments, and for the development of the ground data system for controlling the experiments.

A conceptual design that meets the requirements has been developed (Figure 1). The facility fits in an envelope defined by the available space on the JEMEF porch to be 1x0.8x1.85m. The dewar (Figure 2) carries 260 liters of liquid helium providing six months of lifetime at temperatures between 1.4 and 2.1K for two instruments inserted on opposite sides of the cylindrical facility. The instruments must occupy a volume delineated by a cylinder with a diameter of 20cm and a length of 50cm. A facility electronics enclosure accommodates the dewar housekeeping electronics and the electronics cards to operate the two instruments, including germanium resistor thermometry readouts and servo-loops, SQUID controllers and precision heater drivers. Extra slots are provided for additional experiment dependent electronics such as capacitance bridges, frequency meters, etc. The conceptual design includes a passive vibration isolation system with a resonant frequency of 3Hz, providing a factor of 10 attenuation at 10Hz. The facility will provide output from a 3-axis accelerometer sampled at 250Hz, resolving levels of a few mg up to 100Hz. A charged particle monitor will have a sampling rate of up to 100Hz and a sensitivity of about 2 MeV for protons and heavier particles.

Multiple Instrument Dewar

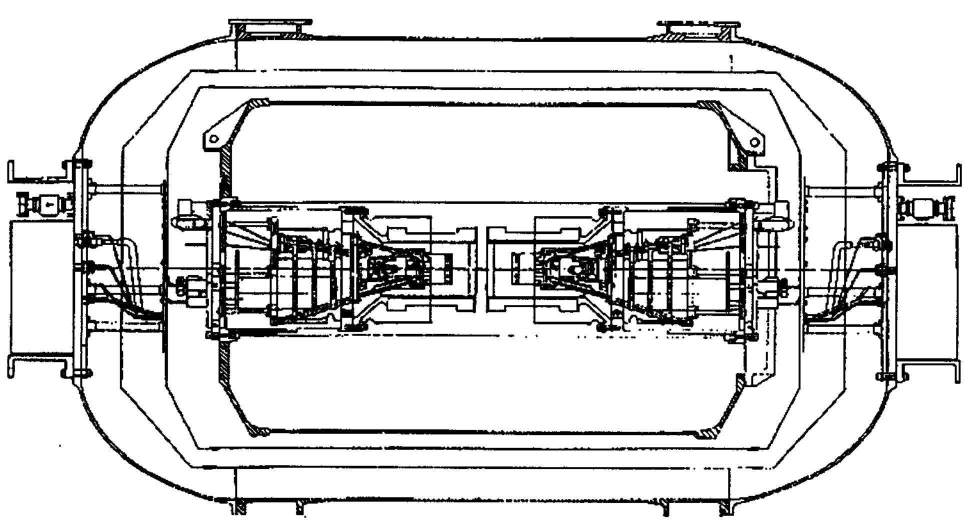

Figure 2

The instrument inserts will be developed at JPL in close cooperation with the individual PIs. The development will be based on a fast prototyping technique. For that purpose, a test facility has been developed and is now operational at JPL. This facility will also support technology development for the instruments to be flown on the LTMPF. It includes a vibration resistant dewar to perform launch load vibration tests at temperatures down to 1.5K on flight instrument inserts, a flight like cryoprobe built with the specifications of the current probe utilized in the Lambda Point Experiment and in the Confined Helium Experiment, associated electronics including accelerometers, data acquisition hardware and software.

4. FACILITY OPERATION

After construction and test of both flight instrument inserts, they would be integrated with the LTMPF at JPL. The instruments would then be cooled down to helium temperatures and would undergo system and environmental tests at JPL. Upon completion of the tests the facility would be shipped cold to Kennedy Space Center for integration with the Shuttle orbiter. The dewar is last serviced on the launch pad prior to payload bay door closure and flies passively attached to an experiment carrier inside the orbiter's cargo bay. Transfer from the orbiter to the space station is accomplished by crew internal vehicle activity using orbiter, Space Station and JEM remote manipulator systems. Turn-on and check out will be performed at the Payload Operations Control Center (POCC) for the space station and routine operations will be conducted from individual remote POCCs located at the investigator facilities. The facility will operate continuously for six months or until the cryogen is spent and then will wait passively to be returned to earth by the STS. Upon return to earth the facility will be fitted with two new experiments and prepared for reflight.

5. CONCLUSION

The Microgravity Fundamental Physics program of the Microgravity Research Division of NASA has experienced significant growth in the early 90's. To meet the need for extended experimentation time in microgravity over the coming decades, NASA and JPL have teamed with industry to develop a Low Temperature Microgravity Physics Facility for use on the International Space Station. The facility attaches outside the Space Station to the Japanese Experiment Module Exposed Facility and provides a 6-month lifetime for operation of two instruments per flight. The international scientific community is invited to participate in developing science experiments for this facility via the NASA Research Announcement process. The first flight of the facility is targeted for the year 2003.

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